

III. An Account of the Appearance of Mercury, passing over the Sun's Disk, on the 29th of October, 1723 determining the mean Motion, and fixing the Nodes of that Planet's Orb. By Edmund Halley, LL. D. Astron. Reg. and R. S. S.

THE Transit of the Planet *Mercury*, over the Disk of the *Sun*, being one of the most curious and uncommon Appearances that the Heavens afford, our Astronomers, both at home and abroad, made due Preparation to observe, with the utmost Exactness, that which happened on the 29th of *October*, 1723, which I had predicted in the Year 1691 (*Phil. Trans.* N° 193.) would be, in Part, visible in *England*. And the Sky proving, more than ordinary, favourable at that Time, we were enabled to observe the Ingress on the *Sun's Limb*, with the greatest Accuracy.

Accordingly, the same Day, *Oktob.* 29. *fly. vet.* at *Greenwich* in the *Royal Observatory*, I first perceiv'd, with my 24 Foot Tube, the *Planet* making a small Notch in the *Sun's Limb* at $2^h\ 41' 23''$ *T. app.* And at $2^h\ 42' 26''$ he was wholly enter'd, making an interiour Contact, the Light of the *Sun's Limb* just beginning to appear behind his dark Body; which, notwithstanding the Slowness of the Motion, was, in a Manner, instantaneous. Then, applying the *Micrometer* to the said 24 Foot Tube, I open'd it so as to take in $16' 15''$ equal to the *Sun's* *Seindiameter* at that time; and causing the northern Edge of the *Sun*, to move exactly along one of the Pointers, I waited till the Center of

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Mercury came to move along the other, as I found it to do at $3^{\text{h}} 1' 16''$ *T. app.* But *Refraction* contracting this Difference of Declination about 5 Seconds (the *Sun* being then but about 11° high) I concluded that the Centers of the *Sun* and *Mercury*, were truly in the same Parallel of Declination at $3^{\text{h}} 3' T. app. proxime.$

At *Wansted* in *Essex* my worthy Colleague, the Rev. Mr. *James Bradley*, *Savilian Professor of Astronomy*, observ'd with the *Hugenian Telescope*, of above 120 Foot long, the total Immersion, or interiour Contact of the Limbs, at $2^{\text{h}} 26' 45''$ *T. æq.* that is $2^{\text{h}} 42' 38''$ *T. app.* twelve Seconds later than I found it at *Greenwich*; most of this Difference being due to the Difference of our Meridians. And applying the *Micrometer* to that vast *Radius*, he measured the Diameter of the *Planet* $10' 45''$. At $2^{\text{h}} 48' 57''$ he found the Difference of Declination between the southern Limbs of the *Sun* and *Planet* by the *Micrometer*, in a fifteen Foot Tube, to be $15' 19''$. Wherefore, allowing the observ'd Semidiiameter of the *Planet*, and the *Refraction*, the said Difference was nearest $15' 30''$, and consequently, *Mercury* more southerly than the *Sun's* Center in respect of Declination $0' 45''$.

Mr *George Graham*, in *Fleet-street, London*, observ'd the first Impression on the *Sun's* Limb at $2^{\text{h}} 41' 9''$ *T. app.* and at $2^{\text{h}} 42' 19''$ *Mercury* was intirely within the Disk. At $3^{\text{h}} 6' 41''$ he measur'd with a *Micrometer*, in a twelve Foot Tube, the Distance of his Center from the nearest Limb of the *Sun* $2' 13''$. And again, at $3^{\text{h}} 25' 24''$ their Distance was found $3' 57''$. At $3^{\text{h}} 34' 43''$ he measur'd the Difference of Declination, from the northern Limb of the *Sun* $14' 57''$, which, corrected by *Refraction*, becomes $15' 4''$, that is, $1' 11''$ more northerly than the *Sun's* Center.

In the *Observatory at Paris*, Signor *Maraldi* observed the first Appearance of *Mercury* on the *Sun's Limb* at $2^{\text{h}}\ 50' 13''$ *T. app.* and the interiour Contact at $2^{\text{h}}\ 51' 48''$. And Mr. *de Lisle*, observing a-part, concluded the same at $2^{\text{h}}\ 51' 37''$, but suspects it might have been some few Seconds later. This Gentleman has communicated his Observation at large, from whence we shall only borrow the following observed Latitudes.

	h f "		h f "
At	$2\ 56\ 20$	<i>Latitudo Borea Mercurii</i>	$3\ 36$
	$3\ 00\ 40$		$3\ 42$
	$3\ 10\ 20$		$3\ 46$
	$3\ 16\ 12$		$3\ 55$

At *Bononia*, in *Italy*, Signor *Manfredi* observed *Mercury* indenting the *Sun's Limb* at $3^{\text{h}}\ 26' 22''$; and that he was gotten entirely within, at $3^{\text{h}}\ 27' 45''$. And these are the Observations most to be depended on, that we have receiv'd from abroad.

In order to deduce from this *Phænomenon*, so accurately observ'd, what may contribute to the Perfectioning of the Theory of *Mercury's Motion*, which (as appears by the near Agreement of our Numbers with this and many other Observations of him) seems to need but very little Correction; I carefully computed, from our Tables, the Motion of the Planet in five Hours, and found his apparent Motion on the *Sun*, to be in Longitude $29' 21''$ Retrograde, and that his Latitude encreas'd northerly $4' 17\frac{1}{2}''$ in the same time; whence the Horary Motion in Longitude $5' 52''$, and in Latitude $0' 51\frac{1}{2}''$, and thence the Angle of the visible Way with the Ecliptick $80' 19'$, and the Horary Motion in that Way $5' 56''$. Again, the Angle of the Ecliptick with

with the Meridian, being in this Place $73^{\circ} 24'$, the visible Way of *Mercury*, made an Angle of $65^{\circ} 5'$ with the Meridian passing through the Center of the *Sun*, whence the Horary Change of Declination becomes exactly $2' 30''$.

These *Data* I choose rather to take from the Theory, than from immediate Observation ; because there is always an unavoidable, tho' small Uncertainty, in what we observe, yet greater than there can be in the Computation for so small a Space of Time, especially now the Theory is, as I said before, so very near the Truth.

This premised, let us now enquire the true Time of the central Ingress, and the Latitude of the Planet at that Time. And first, by my own Account, *Mercury* was gotten into the Parallel of the *Sun's* Center, $21\frac{1}{2}$ Minutes after the central Ingress, in which Time he ascended to the *Northward* $0' 54''$, and so much, therefore, was he more *Southerly* than the *Sun's* Center at his Ingress. Mr. *Bradly*, $7\frac{1}{2}$ Minutes after the said Ingress, in which the Planet ascended $0' 19''$, found his Declination $0' 45''$ South, and therefore at the Ingress, his Declination was $1' 4''$ South. And by Mr. *Graham's* Observation, *Mercury* was more northerly than the *Sun's* Center $1' 11''$, $53' 20''$ after the central Ingress ; but in that Time, *Mercury* ascended $2' 13''$, wherefore, according to him, at the Ingress the Planet had $1' 2''$ South Declination. We shall not therefore err above a Semidiiameter of *Mercury*, if we assume his Declination, at that Time, to have been precisely one Minute.

Now the *Sun's* Semidiiameter being then $16' 15''$, one Minute is the *Sine* of $3^{\circ} 32'$ in the Arch of the *Sun's* Limb ; and consequently, the Point of this Ingress was $13^{\circ} 4'$ more northerly than the Ecliptick ; whence the Latitude of *Mercury* was then $3' 40''$ North, and

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Difference of Longitude $15^{\circ} 50''$, by how much he, at that Time, follow'd the *Sun's* Center.

If therefore, to the Arch of $13^{\circ} 4'$, we add the Double of $8^{\circ} 19'$, or of the Angle which the visible Way made with the Ecliptick, we shall have $29^{\circ} 42'$ for the Point on the *Sun's* western Limb, at which the Planet made his *Exit*, likewise to the North of the *Ecliptick*. Hence the Chord, describ'd in the whole Tranlit, was of $137^{\circ} 14'$, and the Chord itself $30' 16''$; and the nearest Distance to the *Sun's* Center $5' 56''$. Now the Horary Motion in this Chord, being $5' 56''$, the whole Duration of this *Mercurial Eclipse* becomes $5^{\text{h}} 6'$ in respect of the Center of the *Planet*; and therefore the nearest Approach of their Centers was at $5^{\text{h}} 14' 30''$ at *Greenwich*, and the *Exit* at $7^{\text{h}} 47'$; both visible in our *American Plantations*, had there been any curious Person there qualified to observe them.

It follows likewise, by the observ'd Diameter of *Mercury*, $10'' 45'''$ that he was very little less than two Minutes of Time in passing the Limb; and, by the given nearest Distance to the *Sun's* Center, it is concluded that he was in Conjunction, in Point of Longitude, at $5^{\text{h}} 23' 15''$ having then precisely $6' 00''$ North Latitude. Nor can it be doubted, but that all this would have been found exceeding near to Truth, had not the too early setting of the *Sun* deprived all *Europe* of the desirable Sight.

There being a very remarkable *Period* of the Motion of *Mercury* in 46 Years, in which Time, he makes 191 Revolutions about the *Sun*; this Transit of ours is found to have been preceded by two others at that Interval: The first, in the Year 1631, when *Gassendus* at *Paris*, on the 28th Day of *October*, *styl. vet.* was the first that ever observ'd this Appearance of *Mercury* within the *Sun's* Disk, and found him to pass off

at $10^{\text{h}} 28'$ mane. The second was, Octob. $28^{\circ} 1677$, when myself had the good Fortune to observe both the Ingress and Egress of the Planet in the Island of *St. Helena*; the middle Time, when he was nearest to the Sun's Center, being there but $3' 50''$ past Noon, and the visible Duration of the Transit of the Center of the Planet $5^{\text{h}} 14' 20''$; which was some small matter contracted by Parallax, and most likely might have been $5^{\text{h}} 15' 00''$ without it. Now in $5^{\text{h}} 15'$, *Mercury* describ'd the Chord of $146^{\circ} 52'$ in the Sun's Limb, being $31' 9''$, and consequently the nearest Distance to the Center was $4' 38''$, or the Sine of $16^{\circ} 34'$ the Sun's Semidiameter being Radius; that is, $1' 18''$ less than we found it in 1723 . Hence also it follows, that the true Conjunction in Longitude was 7 min. of Time later than the nearest Approach of the Centers, viz. at $0^{\text{h}} 10' 50''$ at *St. Helena*, or at $0^{\text{h}} 35'$ past Noon at *Greenwich*: and, that the North Latitude of the Planet, at that Time, was $4' 41''$.

Supposing, therefore, the nearest Distance of the Centers in the Transit of 1631 , to have been $3' 20''$, that is, $1' 18''$ less than in 1677 , we shall find that *Mercury* then describ'd a Chord of $156^{\circ} 20'$, traversing the Disk of the Sun in $5^{\text{h}} 21' 30''$; so that supposing his Exit at $10^{\text{h}} 28'$ at *Paris*, that is $10^{\text{h}} 18' 40''$ at *Greenwich*, he enter'd on the Sun at $4^{\text{h}} 57' 10''$ in the Morning; and was nearest his Center at $7^{\text{h}} 38' T. app.$ but in the same Longitude with him at $7^{\text{h}} 43'$, or Octob. $27^{\circ} 19^{\text{h}} 43' T. app.$ having then $3' 22''$ North Latitude.

And here, I think I may, without Vanity, advertise the Reader, that above thirty Years since, viz. in *Philosoph. Transf.* N^o 193, for the Month of March, &c. $169\frac{1}{2}$, I predicted, by Help of the two former, this last Transit, with a surprising Exactness, Vol. XXXIII.

even beyond my Hopes, making the Time of the middle, or nearest Approach of the Centers of the *Sun* and *Mercury*, *Anno 1723, Octob. 29^d 5^h 19' T. app.* which we found by Observation at $5^h 14\frac{1}{2}'$, only $4\frac{1}{2}'$ Minutes sooner ; and, in Latitude, *Mercury* was but six Seconds more southerly than I then had computed it ; the Error, in Longitude, being little more than two Diameters of this exceeding small Planet ; and, in Latitude, but a single Semidiameter thereof. So, that for the Future, Astronomers may trust my Table of these Transits, in *Transact. N^o 193*, to a few Minutes of Time, and not wait with the Uncertainty of Hours, nay Days, as has lately been done.

But, in order to obtain a yet further Degree of Exactness by Help of this Observation, it may be most expedient to compare with it the Ingress I observ'd at *St. Helena* ; because, in that, as well as in this, the Latitudes of the Planet being very small, a little Error in them will not so much affect the Longitudes. Supposing therefore, that *Anno 1677, Octob. 27° 21^h 26' 15"* at *St. Helena*, or $21^h 50' 15''$ *T. app.* at *Greenwich*, the Center of *Mercury* entered on the *Sun*, and that, at that Time, he was $8\frac{1}{4}$ Degrees on the *Sun's* Limb, to the North of the Ecliptick (according to what is above concluded) it follows, that he had then $2' 20''$ North Latitude, and $16' 5''$ greater Longitude than the *Sun's* Center ; as in this present Transit, *Octob. 29° 2^h 41' 30'' T. app.* at *Greenwich*, he had $3' 40''$ North Latitude, and $15' 50''$ more Longitude.

Now the apparent Geocentric Differences of Longitude, are to the real Heliocentric Differences, as the Planet's true Distance from the *Sun*, to his Distance from the *Earth* ; that is, in both Cases, as 313 to 676 ; wherefore, in 1677, *Mercury* wanted $34' 45''$ of the Conjunction with the *Sun* ; and, in 1723, but $34'' 13'$, at

at the Times of his apparent Ingress on the Disk. And, equating the Times, I find, that the *Sun, Anno 1677, Octob. 27^d 21^h 34' 20"* *T. æq.* was, in π $15^{\circ} 36' 55''$ and, consequently *Mercury's Heliocentrick Place* $\propto 15^{\circ} 2' 10''$: and, *Anno 1723, Octob. 29^d 2^h 25' 30"* *T. æq.* the *Sun* was in π $16^{\circ} 39' 43''$, and therefore *Mercury*, at that Time, in $\propto 16^{\circ} 5' 30''$.

Mercury therefore, in 46 Years with 11 Intercalations, and besides $1^d 4^h 51' 10''$, has made 191 Revolutions to the Equinoctial Points, and over and above $1^{\circ} 3' 20''$. But, by the *Scholion to Prop. XIV. Lib. III. Natur. Philosoph. Principia Math.* the Motion of the *Aphelion of Mercury*, from the Equinox in that Time, is $40' 18''$; so that there remains $23' 2''$ of *True Anomaly* to be reduced to the *Mean*: Now the Mean Anomaly of *Mercury*, in both Cases, being 5 *fig.* $12^{\circ}, 23' 2''$ of *True Anomaly* gives $15' 24''$ Mean Anomaly; which added to $40' 18''$ becomes $55' 42''$, for the Mean Motion above so many Revolutions: and this is to be encreased by $8''$ to reduce it to the Plane of *Mercury's Orb*, in all $55' 50''$.

Hence, doubling the Interval, in 92 *Julian Years* $1^d 9^h 42' 20''$, the Mean Motion of *Mercury* from the Equinox is $o^s 1^{\circ} 51' 40''$, from which, taking $5^{\circ} 44' 50''$ the Motion in $1^d 9^h 42' 20''$, we have his Motion in 92 *Julian Years* $11^s 26^{\circ} 6' 50''$, and in 100 Years, $2^s 14^{\circ} 2' 13''$, which is but $20''$ more than I had some Years since printed it, in my Astronomical Tables shortly to be published, and differs but one Hour's Motion therefrom in 3000 Years.

The forementioned Proportion of the Distances, *viz.* 313 to 676, is also between the Latitudes seen from the *Earth* and the Inclinations, or Heliocentrick Latitudes of the Planet: so that $2' 20''$, at the Ingress of 1677, gives $5' 2''$; and $3' 40''$ in 1723, becomes $7' 55''$

for the Latitudes at the *Sun*. And the Inclination of the Orb of *Mercury* to the Plane of the Ecliptick (determined by accurate Observations near his northern Limit) being $6^{\circ} 59' 20''$, we compute the Distance of the Planet from his Node, in the former $0^{\circ} 41' 7''$, and, in the latter, $1^{\circ} 4' 37''$; which, being deducted from h's Heliocentrick Places respectively, leave the Place of the ascending Node, in 1677, $\vartheta 14^{\circ} 21' 3''$; and, in 1723, $\vartheta 15^{\circ} 0' 53''$: So, that in 46 Years the Node is found $39' 50''$ forwarder in the Ecliptick; which is but $1' 30''$ more than the Praecession of the Equinox in the same Time. We may therefore safely assume the Plane of the Orb of *Mercury* to be immoveable in the Sphere of fix'd Stars, and its ascending Node to be c^s $15^{\circ} 41'$ from the *first Star of Aries*. Nor can so very slow a Motion (supposing such to be) be fully defined, but by the utmost Care and Diligence of future Astronomers, after the Observation of many Ages.

As to the rest of the Theory of this Planet's Motion, I make his mean Distance from the *Sun*, 38710 such Parts as the mean Distance of the *Sun* and *Earth* is 100000; and his greatest Equation $23^{\circ} 42' 37''$. The *Epocha* of his middle Motion, *in eunte Anno 1723, styl. vet.* from the Equinoctial Point, I make $\varphi 19^{\circ} 9' 31''$; and that of his Aphelion to the same Time $\varphi 13^{\circ} 3' 34''$: the Aphelion moving *secundum Seriem Signorum*, seven Minutes in eight Years. And these Numbers I presume, may represent the Motion of *Mercury*, with an Exactness equal to that of any of the other Planets; perhaps as near as the *Sun's* Place by any Tables, or those of the fixed Stars by any Catalogue yet extant.

It were to be wished, that some good Observation, like this, had been made of the like Transit of *Mercury* at his other Node in *April*, where he was seen indeed

deed *April 23^o 1661*, but so imperfectly, that neither Ingress nor Egress was any where observ'd; and, though it be certain, that he traversed the *Sun* on *April 26^o, 1674*; and again *April 24, 1707*, yet we were so unfortunate, that the Conjunction in both happened so near Midnight, that he escaped unseen by all the Astronomers of *Europe*, excepting singly Mr. *Roe-mer* at *Copenhagen*, whose Observation I have lately received by the Favour of Mr. *De l' Isle* the Astronomer, communicated in the Words of the Manuscript Journal of Observations of the said Mr. *Roe-mer*.

*"Hodie sexto Maii (Anno 1707) hora matutina
" 4^h 19', spectabatur Mercurius in extremo margine
" Solis jamjam exiturus; altus supra imum solis
" marginem & diametri solaris, & ad sinistram in
" Tubo (sc. invertente) Accuratus hæc determi-
" nare non licuit ob moram nimis brevem."* It was great Pity, that he did not, at least, estimate, how many Diameters of his Body he was distant from the Limb of the *Sun*, or what Part of a Diameter, if so near: But having examined this Observation, I find that the *Sun*, at that Time, was but just risen, or rather rising, and soon after entered into a Cloud, so that the Limb of the *Sun* could not be distinctly seen, it always undulating and sparkling much, when so near the Horizon; in which Circumstance, a just Observation could hardly be made.

Let us now see how our Numbers, corrected as above, will represent this Observation. *Anno 1707, April 24^o 16^h 19'* at *Copenhagen* is *15^h 28'* at *Greenwich*, but *15^h 24 20"* *T. æq.* To this Time, I find the *Sun's* true Place $\propto 14^{\circ} 50' 1''$, and his Distance from the *Earth* 101005 . The correct *Epocha* of *Mercury's* mean Motion, for the Year *1707*, is $3^{\circ} 13' 18'' 45''$, to which adding, for the rest of the Time, $3^{\circ} 19' 9'' 28''$,

we shall have his middle Motion at the Time of the Observation in $2^{\circ} 28' 13''$; and, taking his *Aphelion* in $2^{\circ} 12' 49' 49''$ therefrom, we have his mean Anomaly $10^{\circ} 19' 38' 24''$, and thereby the Equation to be added $12^{\circ} 39' 41''$, and thence the Place of *Mercury* in his Orb in $15^{\circ} 7' 54''$. But the correct Place of the descending Node is in $14^{\circ} 46' 25''$, and therefore *Mercury*, being $21' 29''$ past the Node, had $2' 36''$ South Latitude at the *Sun*; and his Place, reduced to the Ecliptick, was in $15^{\circ} 7' 45''$, that is, $17' 44''$ past the Conjunction of the *Sun*, which diminished in the Proportion of 5567 to 4533, or of the Distance of the Planet from the *Earth* to his Distance from the *Sun*, becomes $14' 27''$; and by so much was he past the Conjunction as viewed from the *Earth*. Again, by the same Proportion, his Geocentric Latitude, at that Time, was $2' 7''$ South; and therefore, his apparent Distance from the *Sun's* Center, was $14' 37''$; that is, but $1' 18''$ from his western Limb; so that he might well be said to be, *jamjam exiturus*.

But, that *Mercury* should at that Time be so far northerly, as Mr. *Roemer*'s Words import, was absolutely impossible; and, I am apt to believe, that so acute an Astronomer as Mr. *Roemer* was, could not himself be the Observer, but some Person less acquainted with these Matters; which the Words *spectabatur Mercurius*, instead of *Mercurium vidi*, seem to import. If he had then had North Latitude, he must needs have been seen in the *Sun* in *April 1720*, which we are assured he was not.

Lastly, it may not be amiss to advertise, that on the last Day of *October 1736*, *Mercury* will again traverse the northern Part of the *Sun's* Disk, both Ingress and Egress being visible to all *Europe*.